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"Keep it Simple!"

An Eye-tracking Study for Exploring Complexity and Distinguishability of Web Pages for People with Autism

Sukru Eraslan · Yeliz Yesilada · Victoria Yaneva · Le An Ha

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Abstract A major limitation of the international well-known standard web accessibility guidelines for people with cognitive disabilities is that they have not been empirically evaluated by using relevant user groups. Instead, they aim to anticipate issues that may arise following the diagnostic criteria. In this paper, we address this problem by empirically evaluating two of the most popular guidelines related to the visual complexity of web pages and the distinguishability of web-page elements. We conducted a comparative eye-tracking study with 19 verbal and highly-independent people with autism and 19 neurotypical people on eight web pages with varying levels of visual complexity and distinguishability, with synthesis and browsing tasks. Our results show that people with autism have a higher number of fixations and make more transitions with synthesis tasks. When we consider the number of elements which are not related to given tasks, our analysis shows that they look at more irrelevant elements while completing the synthesis task on visually complex pages or on pages whose elements are not easily distinguishable. To the best of our knowledge, this is the first empirical behavioural study which evaluates these guidelines by showing that the high visual complexity of pages or the low distinguishability of page elements causes non-equivalent experience for people with autism.

Keywords Eye Tracking · Autism · Accessibility Guidelines · WCAG · Visual Complexity · Distinguishability

Sukru Eraslan · Yeliz Yesilada
Middle East Technical University Northern Cyprus Campus
Kalkanlı, Güzelyurt, Mersin 10, Turkey
E-mail: eraslan.sukru@gmail.com, yyeliz@metu.edu.tr

Victoria Yaneva · Le An Ha
University of Wolverhampton
Wolverhampton, United Kingdom
E-mail: {V.Yaneva,Ha.L.A}@wlv.ac.uk

Online Repository

All the documents and materials of our eye-tracking study (the information sheet, consent form, questionnaire and web pages with their elements) are available in our external online repository at `http://iam-data.cs.manchester.ac.uk/data_files/36`.

1 Introduction

Web accessibility guidelines provide a set of recommendations to make web pages more accessible for people with (and without) disabilities, such as having a simple visual design and making their elements distinguishable from each other. There are many web accessibility guidelines available, but the Web Content Accessibility Guidelines (WCAG)[1] is considered as a standard. The recommendations of WCAG are based on four principles with different objectives: (1) Perceivable, (2) Operable, (3) Understandable and (4) Robust. For example, the objective of the Perceivable principle is to present information and user interface components in ways users can easily perceive, and the objective of the Operable principle is to make user interface components and navigation operable ("the interface cannot require interaction that a user cannot perform"). Under each principle, there are sets of guidelines. For instance, there are four guidelines related to the Perceivable principle: Text Alternatives (Guideline 1.1), Time-based Media (Guideline 1.2), Adaptable (Guideline 1.3), and Distinguishable (Guideline 1.4), where the objective of the Adaptable guideline is to create content which can be presented in different ways such as simpler layout without losing information or structure, and the objective of the Distinguishable guideline is to allow users to see and hear content easily. In WCAG, each guideline also has a set of testable success criteria to check whether or not a web page conforms to that particular guideline.

Although these guidelines are critical for designers to understand the needs of different user groups, especially people with disabilities, unfortunately not many of them are empirically evaluated by relevant user groups. Instead, these guidelines aim to anticipate issues that may arise following the diagnostic criteria of different disabilities, and provide recommendations obtained through qualitative interviews with a small number of individuals [33]. Hence, the web accessibility guidelines for people with cognitive disabilities have been perceived as less concrete[2], have been assigned lower priorities compared to the guidelines for other disabilities and are thus less likely to be implemented in practice [21, 13].

In this paper, we aim to evaluate two of the most popular guidelines related to the visual complexity of web pages and the distinguishability of web-page elements for people with cognitive disabilities with an eye-tracking study. Both

[1] `https://www.w3.org/TR/WCAG21/`
[2] `https://www.w3.org/TR/coga-gap-analysis/`

the visual complexity of web pages and the distinguishability of web-page elements are mentioned in WCAG 2.1, Guideline 1.3 and Guideline 1.4 respectively. In this study, we focus on people with autism as our user group, due to the fact that Autism Spectrum Disorder (ASD) is one of the cognitive disabilities that have been least researched in web accessibility. Autism is defined as "a complex neurobehavioural condition that includes impairments in social interaction and developmental language and communication skills combined with rigid, repetitive behaviours" and is referred to as a "spectrum" because of its wide range of symptoms and severity levels [36]. The prevalence of ASD increased from 0.5 to 14.7 per 1000 children over 1970-2010 [8], thus making people with autism a large and rapidly increasing group of web users. Some people with autism may remain non-verbal and/or have mild, moderate or severe intellectual disability. In contrast, other people with autism may have various degrees of verbal ability, be highly-independent and have normal or above-normal intelligence. As the condition is highly heterogeneous, an individual may have multi-faceted needs and abilities corresponding to multiple dimensions of the spectrum.

We conducted an eye-tracking study with 19 verbal and highly-independent people with autism and 19 neurotypical people on eight web pages. These pages were randomly chosen from the top websites listed by Alexa[3] by ensuring that they had varying complexity and distinguishability levels. In order to assess the complexity of these pages, we used the ViCRAM (Visual Complexity Rankings and Accessibility Metrics) tool [25, 26] because of its high accuracy and public implementation [25, 26]. According to the ViCRAM tool, four of these pages had a simple visual design and other four pages had a complex visual design. The elements of the pages were identified by using the extended VIPS (Vision-based Page Segmentation) algorithm as it has been widely used for segmenting web pages into their elements based on their source code and visual representation [1]. We then assessed the distinguishability of web-page elements by computing the ratio of white spaces to the elements identified by the VIPS algorithm, which we call White Space Ratio (WSR). According to the WSR score, the elements of four pages were highly distinguishable from each other while the elements of the other four pages had lower distinguishability.

We investigated two different kinds of tasks. We asked our participants to (i) browse the pages for 30 seconds (hence they were free to look at whichever elements attracted their attention) and (ii) also complete a synthesis task where they needed to combine multiple facts available on each page to provide a new piece of information. The participants needed to complete both kinds of tasks on all the pages in a counter-balanced random order. This eye-tracking study allowed us to investigate how our participants interacted with the web pages, especially which elements they looked at and which paths they followed in terms of these elements. Figure 1 shows eye movements of one user on one of the internal pages of the Wordpress website. The circles represent the fixations of the user where his/her eyes became relatively immobile. The numbers in the

[3] `https://www.alexa.com/topsites`

Fig. 1 A user scanpath on one of the internal pages of the Wordpress website segmented into their visual elements with the extended VIPS algorithm [1] [Visual Complexity: Low, Distinguishability: High]

circles show the sequence of the fixations. In addition, the lines represent the quick eye movements between the fixations which are referred to as saccades. **Contributions:** By analysing the patterns of information processing of the two user groups based on the eye-tracking data, we show that:

– The two groups have opposite patterns of visual processing for the synthesis and the browsing tasks. When completing synthesis tasks, the two groups make fixations with similar durations but the participants with autism have a significantly higher number of fixations and transitions between elements. Inversely, when the participants freely browse the pages and focus on whichever elements they find interesting, the number of fixations and transitions is similar between the two groups, but the participants with autism group make longer fixations. These differences in their processing strategies show the need for web accessibility guidelines for people with autism. These findings also support and extend the findings of our previous work which show that people with autism tend to differ from neurotypical people while searching for specific items on web pages or spontaneously browsing web pages without any time limit [13].
– High complexity or low distinguishability is associated with focusing on a significantly higher number of elements that are not related to the task

by the participants with autism compared to the neurotypical participants. However, there are no significant differences between these two groups when visual complexity is low or distinguishability is high. To the best of our knowledge, this study is the first empirical study based on user behaviour in the literature which evaluates the two guidelines by illustrating that the high visual complexity of web pages or the low distinguishability of web-page elements affects people with autism and cause non-equivalent experience for people with and without autism. The methodology followed in this study can also be followed to empirically evaluate other international well-known standard web accessibility guidelines.

The paper is organised as follows. We first discuss the related work by highlighting the need for empirical studies to evaluate web accessibility guidelines in Section 2, and explain our eye-tracking study and methodology for evaluating the guidelines related to the visual complexity of web pages and the distinguishability of web-page elements in Section 3. We then present and discuss the results of our analysis in Section 4 and Section 5 respectively. Finally, we provide concluding remarks with some directions for future work in Section 6.

2 Related Work

Many web accessibility guidelines are available for guiding web designers to make websites more accessible for people with disabilities [21, 4]. Among these, the most commonly used one is Web Content Accessibility Guidelines (WCAG) [23], developed by the Web Accessibility Initiative (WAI) of the World Wide Web Consortium (W3C). WCAG aims to meet the needs of all disabled user groups rather than a specific group. However, the problems experienced by people with cognitive disabilities are the least discussed in both WCAG and the literature compared to the problems experienced by people with other disabilities [21, 18, 14]. Because of this reason, the Accessible Platform Architectures (APA) Working Group[4] and the Web Content Accessibility Guidelines Working Group (WCAG WG)[5] joined their efforts into the Cognitive and Learning Disabilities Accessibility Task Force[6] with the aim of producing techniques, understanding, and guidance documents for people with cognitive and learning disabilities. They encourage empirical research studies to identify the challenges encountered by these people.

In our study, we focused on autism which is one of the least studied disabilities. There is a limited number of empirical studies to investigate how people with autism differ from neurotypical people when they interact with web pages. One of these studies was conducted by Deering [9] with only four participants but it did not reveal any differences between the two groups,

[4] `https://www.w3.org/WAI/APA/`
[5] `https://www.w3.org/WAI/GL/`
[6] `https://www.w3.org/WAI/PF/cognitive-a11y-tf/`

possibly due to the lack of statistical power caused by the small sample size. Another empirical study was an eye-tracking study conducted by Eraslan et al. [12]. The study showed that people with autism tend to be less successful in searching for specific items on web pages compared to neurotypical people [12]. It also showed that people with autism are likely to have shorter fixations and a higher number of fixations on web pages, make more transitions between their elements and have more fixations on irrelevant elements [13]. However, these empirical studies did not aim to evaluate any specific web accessibility guideline empirically.

Britto and Pizzolato [5] combined existing guidelines relevant to people with autism. They then categorised these guidelines into the following categories: Engagement, Affordance, Customisation, Redundant representation, Multimedia, Feedback, System status, Navigability and Interaction with a touchscreen. These guidelines originated from nine different countries: the USA, Brazil, Italy, the UK, Israel, India, Malaysia, Chile and Hong-Kong. However, none of them were based on empirical research studies with people with autism. For example, Friedman and Bryen [16] proposed 22 guidelines for people with autism based on a literature review of existing guidelines for people with cognitive disabilities. In addition, Darejeh and Singh [7] proposed some guidelines for people with autism based on other recommendations for people with low literacy. As can be seen from these examples, these guidelines were typically based on literature reviews or relating the diagnostic criteria to potential accessibility barriers [27, 19, 30]. People with autism participated in some studies which aimed to evaluate particular tools and applications, but these studies revealed only a little or no advice on accessibility issues [3, 28, 17, 34, 37].

The autism-specific challenges are provided within the Cognitive Accessibility User Research paper issued by the W3C [33] and these challenges were identified based on the autism diagnostic criteria and an interview with an anonymous user. These challenges indicate that, people with autism:

- "may not pay attention to primary content because distracted by secondary content;
- may be confused by instructions that are not well-defined, transitions among content-delivery types (e.g., text to video), presentations of content using different formats or designs;
- may not participate in web-based interactions with other people;
- may not recall instructions when subsequently presented with an action to perform;
- may react negatively to auto-playing video or audio".

The Cognitive Accessibility User Research paper issued by the W3C [33] then provides a set of recommendations for addressing these challenges. Specifically, it generally recommends having a simple visual design for web pages for avoiding distractions and this recommendation is associated with the WCAG 2.1 Guideline 1.3. It also recommends making the elements of web pages distinguishable from each other by using white spaces and this recommendation is related to the WCAG 2.1 Guideline 1.4. Even though the possible benefits of these recommendations and guidelines are mentioned, they are not evaluated with empirical studies.

Raymaker et al. [32] also developed a set of web accessibility guidelines for web users with autism based on a community-based participatory research approach and then created a website to improve access to healthcare for adults with autism based on those guidelines. The usability of the website was evaluated with 170 end-users with autism. Above 95% of the users indicated the website is easy to use, easy to understand, important, and useful. Hence, Raymaker et al. [32] suggested to use those guidelines to create an accessible website for people with autism. There are also overlaps between those guidelines and the guidelines suggested by the WCAG. For example, both guidelines recommend to provide "simple consistent navigation". Therefore, even though the guidelines of Raymaker et al. [32] were created with a community-based participatory research approach, their impact has not been shown on different websites in terms of user behaviour. Therefore, we can conclude that the overall goal of that work was different from ours.

In this study, we aim to provide the first empirical behavioural evaluation of the international well-known standard guidelines related to the visual complexity of web pages and the distinguishability between web-page elements by using an eye-tracking study.

3 An Eye-tracking Study

We designed an eye-tracking study to investigate the following three research questions. Our study was approved by the Ethics Committee of the University of Wolverhampton. The following research questions were addressed.

1. *Do people with autism have different processing strategies in comparison with neurotypical people while completing their tasks on the web?*
   Anecdotal evidence suggests that people with autism may have different processing strategies on the web. If they have different processing strategies and in particular, they experience difficulties, then they will require alternative designs for efficient interaction on the web. With this research question, we aim to empirically test if there are behavioural differences between people with autism and neurotypical people when interacting with the web, thereby evaluating the need for specific guidelines for people with autism. This question is, therefore, cross-cutting the two other research questions given below.
2. *Does the high visual complexity of web pages affect people with autism while completing their tasks and cause non-equivalent experience for people with autism and neurotypical people?*
   It is recommended to have a simple visual design for web pages (see WCAG 2.1 Guideline 1.3, Britto and Pizzolato [5] on G3 Engagement & Raymaker et al. [32] on intellectual accessibility guidelines). With this research question, we aim to empirically evaluate this recommendation by investigating

whether or not the high visual complexity of web pages affects people with autism when they complete their tasks and causes non-equivalent experience for people with autism and neurotypical people.

3. *Does the low distinguishability of web-page elements affect people with autism while completing their tasks and cause non-equivalent experience for people with autism and neurotypical people?*
   It is also recommended to make the elements of web pages distinguishable from each other (see WCAG 2.1 Guideline 1.4, Britto and Pizzolato [5] on G3 Engagement & Raymaker et al. [32] on physical accessibility guidelines). With this research question, we aim to empirically evaluate this recommendation by investigating whether or not the low distinguishability of web-page elements affects people with autism when they complete their tasks and causes non-equivalent experience for people with autism and neurotypical people.

3.1 Participants

Forty-four people participated in our eye-tracking study. A total of 19 participants had been formally diagnosed with autism and they were considered as ASD-group participants whereas the remaining 24 participants were neurotypical people and they were considered as control-group participants. We recruited our ASD-group participants through a charity organisation in Birmingham and the student enabling centre at the University of Wolverhampton whereas we recruited our control-group participants through snowball sampling.

All of the control-group participants were asked to complete the Autism Quotient (AQ) test to ensure that they were not on the autism spectrum [2]. One of these participants had a high score in the test, and therefore we excluded his/her data from further analysis. The ASD group participants were not asked to complete this test as they had been formally diagnosed with autism. Besides this, we removed the data of three control-group participants as they had dyslexia, and also the data of two control-group participants as they could not have successful calibration with the eye tracker. To have the same number of participants for each group, we also randomly excluded one participant from the control group. Therefore, five out of 24 control-group participants were excluded and we conducted our analysis with 19 people with autism (Female: 8, Male: 11) and 19 control-group participants (Female: 13, Male: 6). The details of our participants are shown in Table 1.

The mean age of the ASD group participants was 41.05 (Std. Dev: 14.04) and the mean age of the control-group participants was 32.15 (Std. Dev: 9.93). Not all the participants provided information about their education. Among the ASD group participants, 17 provided information about their education: 11 of them had a higher education degree and six of them had a UK equivalent of a high-school degree. Among the control-group participants, 18 provided

Table 1 The details of the participants

Details		ASD Group	Control Group
Gender	Female	8	13
	Male	11	6
Age	Mean	41.05	32.15
	Standard Deviation	14.04	9.93
Education	Higher Education	11	15
	High-school	6	3
	Not Provided	2	1
English Level	Native speaker	19	15
	Non-native Fluent	0	4

information about their education: 15 of them had a higher education degree and three of them had a UK equivalent of a high-school degree.

All participants were native speakers of English, except for four control-group participants. However, these four participants lived in the UK for many years and they had a high level of English proficiency. Furthermore, all participants were daily web users, apart from one ASD-group participant who reported that he/she used the web less than once a month.

3.2 Equipment

We used the Gazepoint GP3 eye tracker to record the eye movements of our participants. The sampling rate of the eye tracker was 60 Hz and its degree of accuracy was provided as 0.5-1 degree. The screenshots of eight different web pages were shown to the participants on a 17” monitor with the screen resolution of 1024 x 768. The distance between the participants and the eye tracker was controlled and it was approximately 65 cm.

3.3 Materials

We followed a systematic approach to select web pages for our eye-tracking study. We selected eight web pages by ensuring that they were popular among web users and they were suitable for exploring the effects of the visual complexity of web pages and the distinguishability of web-page elements for people with autism. We started with the list of the top 100 websites from Alexa. We firstly removed the websites which were repeated in the list. For example, we kept `https://www.google.com`, but removed `https://www.google.co.uk`. We removed the non-English websites, the search engines (e.g., `https://www.google.com`) and websites that needed authentication (e.g., `https://www.facebook.com/`).

As we were interested in exploring the effects of the visual complexity of web pages and the distinguishability of web-page elements, we determined the visual complexity level of the home pages of the remaining websites and the distinguishability level between their elements by using the metrics given below. To identify the elements of the pages, we used the extended VIPS algorithm as the VIPS algorithm has been commonly used for dividing web pages into their visual elements based on the source code and visual representation and relating the resultant elements with the underlying source code [1]. It is a crucial feature of the VIPS algorithm as it allows further processing of web pages based on their elements. This algorithm provides visual elements in a hierarchical form where more and smaller elements are available in deeper levels.

Visual complexity level: To identify a visual complexity level, we used the ViCRAM tool to compute a visual complexity score (VCS) for each page which varied between 0 and 10 where higher VCS values represent higher visual complexity [25, 26]. This tool takes a web page with its URL, counts specific structural elements on the web page (i.e., top left corners, images, words) and then uses the total number of each element to compute a VCS score. The formula used to calculate the VCS score is empirically developed with a number of user studies which considered the users' perception as well as the structure of web pages. If the VCS was greater than five, then we considered it as high visual complexity. Otherwise, we considered it as low visual complexity. The ViCRAM tool is implemented in the Accessibility Tools Framework (ACTF) which is a sub-project of the Eclipse Technology Project. ACTF Visualization SDK could be installed[7] and then the Team Project Set File (.psf) of the tool could be imported to Eclipse[8] to run this tool.

Distinguishability level: To identify a distinguishability level, we first eliminated the white spaces out of the page margins and then recursively (from children elements to parent elements) computed the white space ratio (WSR) of each element identified by the VIPS algorithm on each page. Since VIPS algorithm creates a hierarchy of elements, the WSR score of the top element is the overall WSR score of the page. The WSR values were varied between 0 and 1. Higher WSR values represented higher distinguishability between web-page elements. If the WSR was greater than 0.5, then we considered it as high distinguishability, Otherwise, we considered it as low distinguishability.

After determining the visual complexity and distinguishability levels, we had four classes of websites: (Class 1) Low Complexity & High Distinguishability, (Class 2) Low Complexity & Low Distinguishability, (Class 3) High Complexity & High Distinguishability, (Class 4) High Complexity & Low Distinguishability. We then randomly selected two websites from each class as follows: (Class 1) Wordpress & WhatsApp, (Class 2) Outlook & Netflix, (Class 3) YouTube & Amazon, (Class 4) Adobe & BBC (see Figure 2). The VCS and WSR values of these pages are illustrated in Figure 3.

[7] `http://www.eclipse.org/actf/downloads/`

[8] `http://ftp.gnome.org/mirror/eclipse.org/technology/actf/psf/old/anonymous/actf-examples.zip`

Fig. 2 The four classes and the selected websites from each of these classes

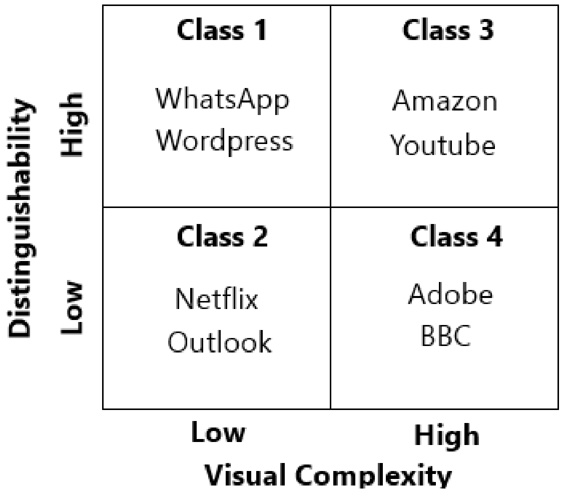
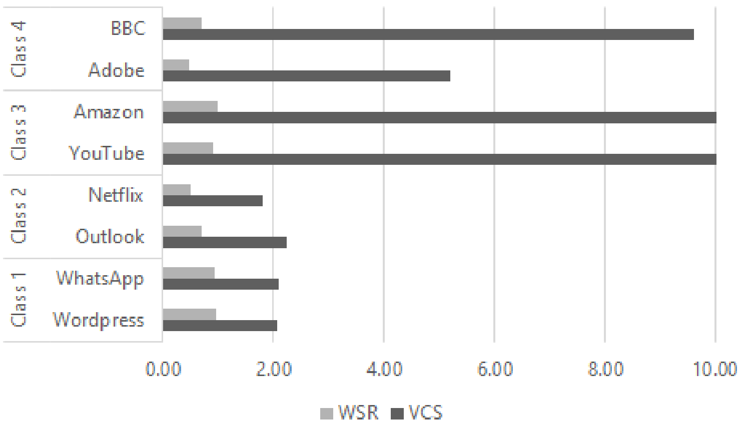


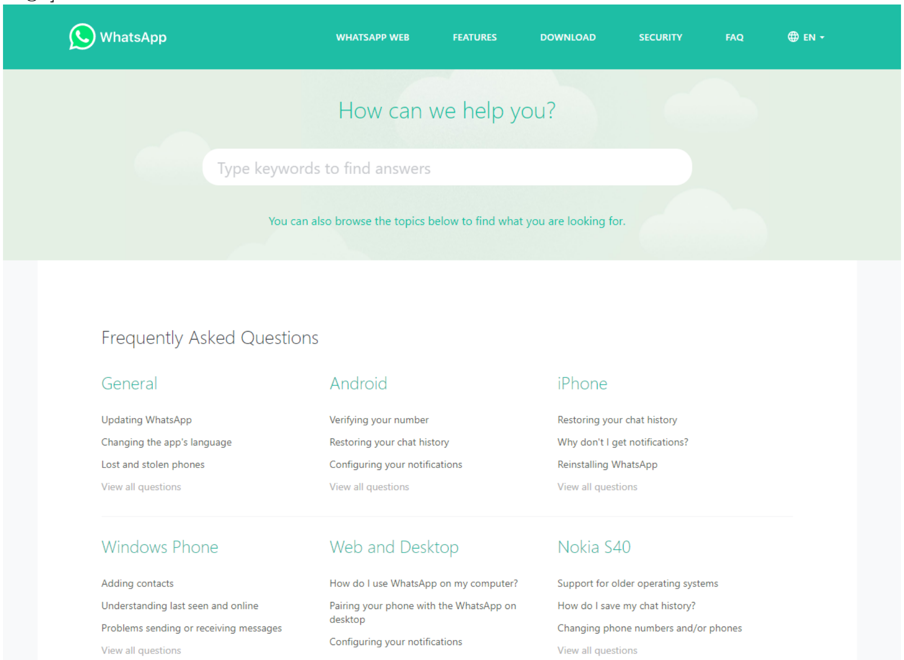
Fig. 3 The VCS and WSR values of the selected pages from four classes: (Figure 2)



In our eye-tracking study, we used the screenshots of the home pages of the Outlook, Netflix, YouTube, Amazon and Adobe websites whereas we used the screenshots of one of the internal pages of the Wordpress, WhatsApp and BBC websites as it was not possible to find more realistic tasks on their internal pages (see Table 2). However, we ensured that a selected internal page of a particular website has the same visual complexity and distinguishability levels as the home page of that website. Figures 4-7 show one of the selected web pages for each class along with their visual complexity and distinguishability levels.

The motivation behind the choice of having screenshots of the pages as opposed to engaging the participants with an actual website interaction was three-fold. First, confounding variables resulting from the interactive use of mouse and keyboard were eliminated, since all necessary information for solving the queries was displayed on the screen. Having multiple pages from various kinds of popular websites allowed better representativeness of the stimuli and a wider coverage of media type. Furthermore, limiting the interaction to the level of a single page at a time as opposed to an entire website ensured that the gaze of all participants was constrained to the same set of visual elements that were immediately available once the page was displayed.

Fig. 4 A page from the WhatsApp website [Visual Complexity: Low, Distinguishability: High]



To test the research questions empirically, we needed to look at some features related to the elements of the web pages (such as the number of transitions between elements for our first research question). Since a study conducted by Akpınar and Yeşilada [1] suggests the fifth level as the most preferred level for the VIPS algorithm by the users with approximately 74% satisfaction, we used the elements at the fifth level. However, we used the deeper levels for some pages because the fifth level was not appropriate for those pages (see Table 2) as the tasks could be completed by fixating only one element. The web pages with their elements are available in our external repository (See Online Repository Section).

Fig. 5 A page from the Netflix website [Visual Complexity: Low, Distinguishability: Low]

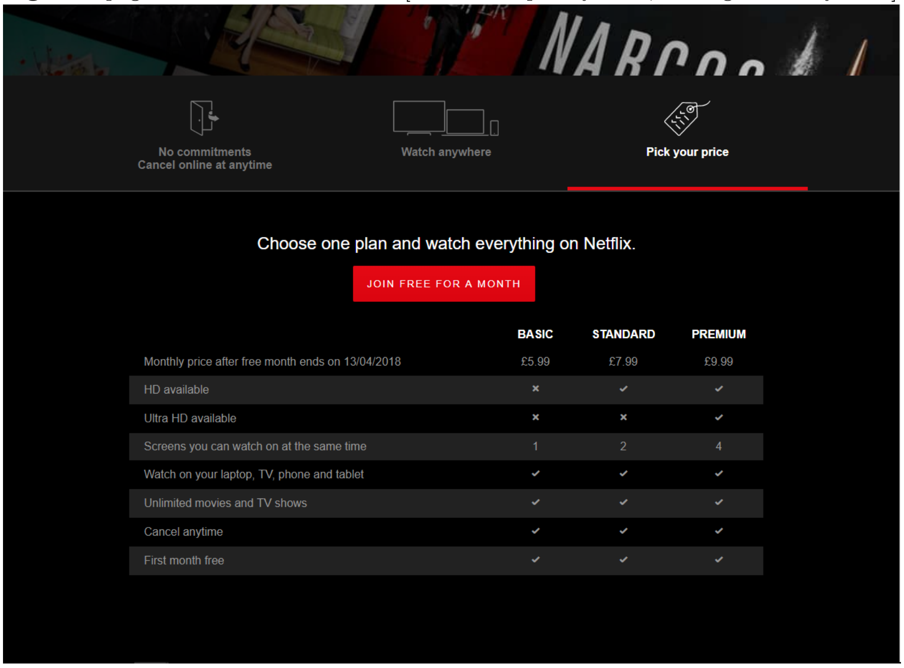


Fig. 6 A page from the Amazon website [Visual Complexity: High, Distinguishability: High]

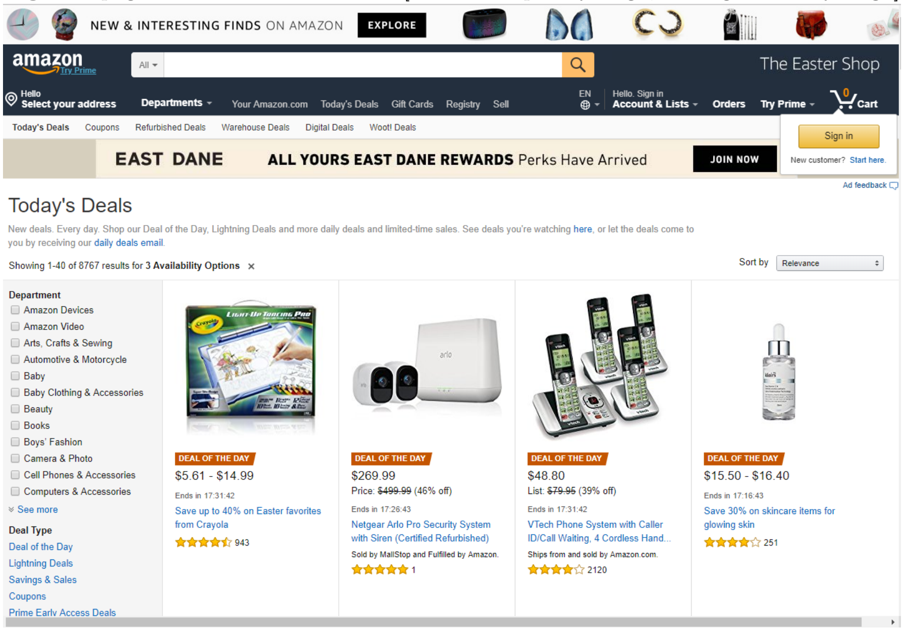
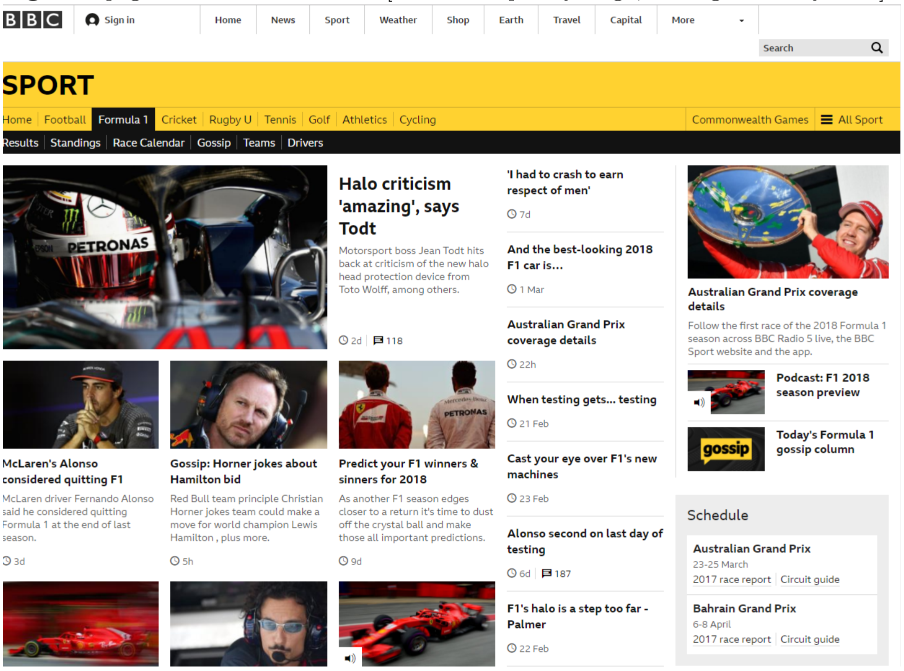


Fig. 7 A page from the BBC website [Visual Complexity: High, Distinguishability: Low]



3.4 Tasks

The participants were asked to complete two different kinds of tasks on the web pages called browsing and synthesis tasks. Both of these are associated with the search activities model of Marchionini [24] which is one of the most popular models in this field. In this model, tasks are split into three main categories: Lookup, Learn and Investigate. Both kinds of our tasks are related to the Investigate group.

In the browsing tasks, we asked the participants to spontaneously browse the web pages for 30 seconds without being required to respond to any questions. However, in the synthesis tasks, we asked them some specific questions. Oxford English Dictionary defines synthesis as "the combination of components or elements to form a connected whole"[9]. The synthesis questions were consistent with the definition. Specifically, the participants needed to combine multiple facts from different elements to provide a new piece of information in maximum 120 seconds to answer the questions. For example, the participants were asked to find the product which has been rated by the largest number of users on the home page of the Amazon website (see Figure 6), and therefore they needed to look at all the available products. The complete list of the synthesis tasks is provided in Table 2.

[9] `https://en.oxforddictionaries.com/definition/synthesis`

Table 2 The web pages with their visual complexity and distinguishability levels & the synthesis tasks for each page

Page	Complexity	Distinguishability	Synthesis Tasks
WhatsApp	Low	High	(a) Under frequently asked questions, what topic features in both the iPhone and Android columns?
			(b) Under frequently asked questions, which sections feature topics relating to notifications?
Wordpress	Low	High	(a) Which of the WordPress plans offers community support instead of email support?
			(b) What is the cheapest plan you can get that offers Email & Live Chat support?
Netflix	Low	Low	(a) Which is the cheapest plan that allows you to watch movies on your laptop, TV and tablet?
			(b) How much more would you have to pay compared to the basic plan if you wanted to have Ultra HD?
Outlook	Low	Low	(a) According to the text, is Twitter a partner app of Outlook?
			(b) The names of which apps are both mentioned in the text and presented as logos below the text?
Amazon	High	High	(a) Which item has the largest price discount measured in percentage?
			(b) Which product has been rated by the largest number of users?
YouTube	High	High	(a) Under the American football category, which videos have been posted within the last three months?
			(b) Under the NBA topic, which video has the largest number of views?
Adobe	High	Low	(a) Which is the product that is targeted to UX designers and for which students can get a discount?
			(b) How many types of clouds are offered by Adobe within this page?
BBC	High	Low	(a) According to the schedule, which Grand Prix takes place first: the Australia or the Bahrain?
			(b) Which of the following sports does not have its own tab on BBC Sport: Golf, Cricket or Valleyball?

While designing the tasks, we ensured that they are very clear and represent general real-life scenarios such as comparing multiple commercial products to select the most suitable one for a specific objective. The tasks were not long (approximately 16 words on average). They were also not associated with the type of social conversations which potentially cause some problems for people with autism such as small talk, reading social cues, etc.

3.5 Procedure

All participants firstly read the information sheet which was about the main objectives of the study and their rights. The procedure was also explained to the participants in depth. Since the real web pages were used in this study and all of our participants were daily web users (apart from one participant), there was no training session. When the participants signed the consent form, they were then requested to complete a short questionnaire which aimed to collect their basic demographic information, including gender, age group, education level and web usage. They were also asked to rank the web pages based on how often they visit them by using five-point Likert scale (Daily: 5, Weekly: 4, Monthly: 3, Less than once a month: 2, Never: 1), which we call familiarity scores. Moreover, the control-group participants were requested to complete the Autism Quotient test as mentioned above. All of these documents are available in our external repository (See Online Repository Section).

When the participants were ready for the eye-tracking sessions, they sat in front of the eye tracker and performed a nine-point calibration. After successful calibration, they started their eye-tracking sessions and completed their tasks by looking at the pages. Since all web pages were presented as screenshots and all the tasks could be completed without any scrolling and real interaction, the participants were not allowed to use a mouse and a keyboard to minimise head movements and other confounding factors.

The participants viewed all the web pages twice for the browsing and synthesis tasks in a random counter-balanced order to deal with any possible order effect. To counteract any possible familiarity effect, half of the participants completed the browsing tasks and then the synthesis tasks whereas another half of the participants completed the synthesis tasks and then the browsing tasks. For each kind of tasks, the order of pages was also randomised for each participant. The researcher was responsible for reading the tasks to the participants and controlling the sessions. When the participants completed their sessions, they were debriefed.

3.6 Methodology

While completing the eye-tracking study, we had a series of fixations for each participant on each web page for both the browsing and synthesis tasks. We firstly represented the scanpaths of the participants in terms of the elements of the web pages by finding the corresponding element of each fixation. We also kept the duration of each fixation (the duration of a fixation is equal to the difference between its start time and end time in milliseconds). For example, if one of the participants looked at three points in the elements A, B and C for 100 ms, 200 ms and 300 ms respectively, then his/her scanpath was represented as A (100 ms), B (200 ms), C (300 ms). Since the web pages were fully segmented into their elements, fixations which were not located in any element were excluded, as those fixations were located in non-meaningful areas (especially, white spaces).

To investigate our research questions, we extracted some features from the individual scanpaths and then compared the ASD and control groups based on these features. Since there were two independent groups in the study, we applied the independent T-Test or its non-parametric alternative the Mann-Whitney U test. When the values of the features were normally distributed within both of the groups, we applied the independent T-test. Otherwise, the Mann-Whitney U test was applied. These tests were applied as one-tailed because we had some expectations on which group have higher values for these features based on a preliminary analysis [13]. We also calculated the effect sizes of the results for the independent T-test (Cohen's d: 0.2 small effect, 0.5 medium effect, 0.8 large effect) and the Mann-Whitney U test (r: 0.1 small effect, 0.3 medium effect, 0.5 large effect) [6, 31].

4 Results

4.1 Processing Strategies

The first research question aimed to investigate whether there were behavioural differences between the ASD and control groups when they completed their tasks on the web. To investigate this question, we extracted the mean fixation duration (i.e., the mean of the fixation durations), the total fixation count (i.e., the total number of fixations), and the number of transitions between the elements for each participant on each web page for both the browsing and synthesis tasks. After that, we calculated the average value for each participant for all the web pages for both the browsing and synthesis tasks. We then compared the ASD and control groups based on each of the features. These three features were selected as they have widely been used in the literature [11]. Fixation duration is typically related to information processing [15, 35]. When users look at unnecessarily more points on web pages while searching for a particular item or a piece of information, their searching behaviours are usually considered as inefficient [11]. Furthermore, when users make more transitions between elements of web pages while searching for a particular item or a piece of information, this situation is typically interpreted as uncertainty in searching [11]. Based on a preliminary analysis conducted by Eraslan et al. [13] with other eye-tracking datasets, we expected that the ASD group participants would have lower fixation durations but they would have higher fixation counts and transitions between different elements.

Table 3 A comparative analysis between the ASD and control groups based on three features on all the pages for the **browsing** tasks [N: Sample Size, M: Mean, MD: Median, SD: Standard Deviation, NA: Not Applicable, *p < .05, **p < .01, ***p < .0001]

Feature	ASD Group				Control Group			
	N	M	MD	SD	N	M	MD	SD
F1	19	322.71	320.05	45.94	19	350.32	341.27	44.7
F2	19	61.12	62.5	10.35	19	61.64	62.5	7.14
F3	19	25.76	26.62	4.16	19	24.7	24	3.91

Feature	Independent T-Test				Mann-Whitney U-Test			
	t	df	p	d	U	z	p	r
F1	NA	NA	NA	NA	119	-1.795	**0.037***	0.29
F2	-0.173	36	0.432	0.06	NA	NA	NA	NA
F3	NA	NA	NA	NA	143	-1.095	0.14	0.18

F1: Mean Fixation Duration, F2: Total Fixation Count, F3: Number of Transitions

Table 4 A comparative analysis between the ASD and control groups based on three features on all the pages for the **synthesis** tasks [39] [N: Sample Size, M: Mean, MD: Median, SD: Standard Deviation, NA: Not Applicable, *p < .05, **p < .01, ***p < .0001]

Feature	ASD Group				Control Group			
	N	M	MD	SD	N	M	MD	SD
F1	19	329.15	322.99	43.58	19	321.47	318.31	27.68
F2	19	84.86	78.5	19.75	19	66.4	63.25	13.05
F3	19	41.76	42.38	8.77	19	35.36	36	7.67

Feature	Independent T-Test				Mann-Whitney U-Test			
	t	df	p	d	U	z	p	r
F1	NA	NA	NA	NA	150	-0.89	0.191	0.14
F2	NA	NA	NA	NA	89	-2.671	**0.004****	0.43
F3	2.331	36	**0.013***	0.78	NA	NA	NA	NA

F1: Mean Fixation Duration, F2: Total Fixation Count, F3: Number of Transitions

The results of our analyses for the first research question are provided in Tables 3 and 4. Table 3 shows the results of the comparative statistical analyses between the ASD and control groups based on the mean fixation duration, the total fixation count, the number of transitions between the elements on all the web pages for the browsing tasks. These results show that the ASD-group participants had significantly longer fixations with the medium effect size in comparison with the control-group participants for the browsing tasks (U=119, z=-1.795, p=.037, r=.29), even though we expected the converse because of previous studies in the literature with other eye-tracking datasets [13]. However, there was no significant difference between the ASD and control-group participants in terms of the total fixation count and the number of transitions between elements for the browsing tasks, even though we expected that the ASD group would have higher fixation counts and transitions between different elements.

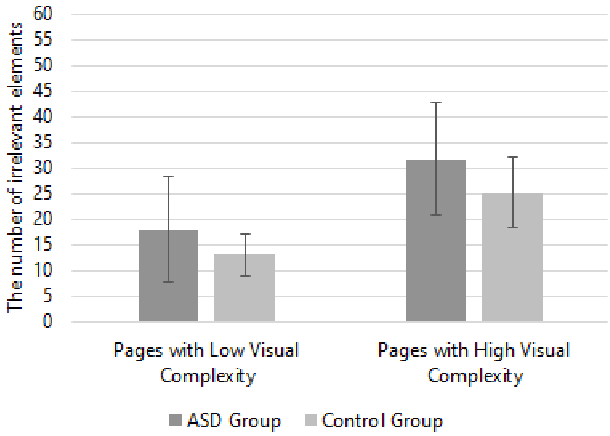
Table 4 illustrates the results of the comparative statistical analyses between the ASD and control groups based on the same three features for the synthesis tasks (see our preliminary analysis in [39]). As can be seen from this table, there was no significant difference between the ASD and control-group participants in terms of the mean fixation duration for the synthesis tasks. However, the results also show that the ASD-group participants had a significantly higher number of fixations with the medium effect size (U= 89, z=-2.671, p=.004, r=.43) and made significantly more transitions between the elements with the large effect size in comparison with the control-group participants (t=2.331, df=36, p=.013, d=.78) while completing their synthesis tasks. Hence, these results support our expectations regarding the number of fixations and the number of transitions between different elements. Overall, the results of our analyses for the first research question suggest that there can be behavioural differences between people with autism and neurotypical people on the web, thereby empirically demonstrating the need for specific web accessibility guidelines for people with autism.

4.2 Visual Complexity

The second research question aimed to investigate the effect of the visual complexity of web pages for people with autism while completing their synthesis tasks. Since it was suggested that people with autism tend to be distracted by irrelevant details while completing their tasks [20], we decided to extract the number of fixations on the elements which were not related to the synthesis tasks for each participant on each web page. We then calculated the average value for each participant on visually complex and visually simple pages separately and compared the two groups based on them. The irrelevant elements were identified based on the synthesis tasks. For example, on the Amazon website (see Figure 6), the participants needed to look at all the available products on the home page to complete their synthesis tasks, and therefore the elements with the products were identified as relevant elements and other elements were identified as irrelevant elements. We expected that the ASD group participants would have higher fixations on the irrelevant elements on the visually complex pages where there would be no difference between the ASD and control-group participants on the visually simple pages.

Figure 8 shows a comparison between the ASD and control groups based on the number of irrelevant elements on the web pages with low and high visual complexity levels for the synthesis tasks for the second research question. The ASD group participants looked significantly more irrelevant elements on the visually complex web pages with the medium effect size in comparison with the control group participants (U=108, z=-2.117, p=.018, r=.34) and there was no significant difference between these two groups on the visually simple pages (U=127.5, z=-1.547, p=.063, r=.25). These results show that the high visual complexity of web pages affects people with autism while completing their tasks and causes non-equivalent experience for people with autism and neurotypical people, and therefore validates the guideline related to the visual complexity of web pages.

Fig. 8 A comparison between the ASD and control groups based on the number of irrelevant elements on the web pages with the low and high visual complexity levels for the synthesis tasks

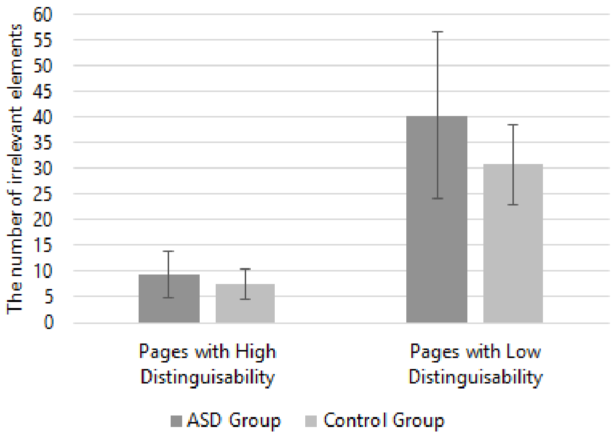


4.3 Distinguishability

The third research question aimed to investigate the effect of the distinguishability of web-page elements for people with autism while completing their synthesis tasks. Similar to the analysis of the second research question, we first extracted the number of fixations on the irrelevant elements for each participant on each web page and then calculated the average value for each participant on the web pages with the low and high distinguishability levels separately. After that, we conducted a comparative analysis between the two groups based on them. We expected that the ASD group participants would have higher fixations on the irrelevant elements on the web pages with the low distinguishability level where there would be no difference between the ASD and control-group participants on the web pages with the high distinguishability level.

Figure 9 illustrates a comparison between the ASD and control groups based on the number of irrelevant elements on the web pages with the low and high distinguishability levels for the synthesis tasks for the third research question. The ASD group participants looked significantly more irrelevant elements on the web pages with low distinguishability with the medium effect size in comparison with the control-group participants (U=111.5, z=-2.014, p=.023, r=.33) and there was no significant different between these two groups on the web pages with the high distinguishability level (U=146.5, z=-0.993, p=.164, r=.16). These results show that the low distinguishability of web-page elements affects people with autism when they complete their tasks and causes non-equivalent experience for people with autism and neurotypical people, and therefore validates the guideline related to the distinguishability of web-page elements.

Fig. 9 A comparison between the ASD and control groups based on the number of irrelevant elements on the web pages with low and high distinguishability levels for the synthesis tasks



4.4 Familiarity to Web Pages

We compared the familiarity scores given by the participants in the two groups to ensure that there were no difference in terms of familiarity on the pages between the groups. Table 5 shows a comparative analysis between the ASD and control groups based on the familiarity scores given. As can be seen from this table, no significant difference was detected between these two groups in terms of the familiarity to the web pages, and therefore we can suggest that there is no familiarity effect between groups on our findings.

5 Discussion

In this study, we focused on three different research questions (see Section 3). The first research question was related to the empirical illustration of behavioural differences between people with and without autism on the web, thus demonstrating the need for specific web accessibility guidelines for people with

Table 5 A comparative analysis between the ASD and control groups based on the familiarity scores (Daily: 5, Weekly: 4, Monthly: 3, Less than once a month: 2, Never: 1) that they gave for the web pages [N: Sample Size, M: Mean, MD: Median, SD: Standard Deviation, NA: Not Applicable, Bonferroni correction $\alpha = 0.00625$]

Page	ASD Group				Control Group				Mann-Whitney U-Test			
	N	**M**	**MD**	**SD**	**N**	**M**	**MD**	**SD**	**U**	**z**	**p**	**r**
WhatsApp	19	1.53	1	1.23	19	2.42	2	1.63	108.5	-2.102	0.015	0.34
Wordpress	19	1.16	1	0.36	19	1.47	1	0.6	131.5	-1.431	0.073	0.23
Netflix	19	2.42	2	1.53	19	3.05	4	1.5	138.5	-1.226	0.203	0.2
Outlook	19	2.74	2	1.8	19	2.89	2	1.59	164.5	-0.467	0.637	0.08
Amazon	19	3.32	4	1.13	19	3.84	4	0.67	133.5	-1.372	0.134	0.22
YouTube	19	4.05	4	1.1	19	4.37	5	0.87	152	-0.832	0.366	0.13
Adobe	19	1.63	1	1.04	19	1.68	1	1.08	174.5	-0.175	0.854	0.03
BBC	19	3.32	3	1.17	19	4	4	1.03	123	-1.679	0.082	0.27

autism. Our analysis clearly illustrates the significant differences between these two groups for the mean fixation duration for the browsing tasks and the total fixation count and the number of transitions between the elements for the synthesis tasks (see Section 4.1). In the browsing tasks, we did not detect a significant difference between these two groups for the total fixation count and the number of transitions between the elements. The reason for this could be the fact that the participants spontaneously browsed the pages without the need for answering specific questions. In the synthesis tasks, we did not detect a significant difference between these two groups for the mean fixation duration. This situation could also be caused by the task type as the participants needed to answer specific questions in maximum 120 seconds for the synthesis tasks.

The second and third questions were related to the empirical investigation of the effects of the visual complexity of web pages and the distinguishability of web-page elements on the behaviour of people with and without autism. Our analysis suggests that the high visual complexity of web pages or the low distinguishability of web-page elements affects people with autism when they complete their tasks as they are more distracted by irrelevant elements on visually complex pages or on web pages whose elements are not easily distinguishable (see Section 4.2 and Section 4.3). These results empirically support the challenge reported by Seeman and Cooper [33] in the research paper issued by the W3C: People with autism "may not pay attention to primary content because distracted by secondary content" (see Section 2). These results also support the guidelines proposed by Raymaker et al. [32] which also highlight the importance of simplicity. Therefore, web designers should keep their web pages simple and make their elements distinguishable from each other as much as possible.

In the present study, we focused on autism which is one of the least discussed cognitive disabilities. Even though the participants with autism were daily web users (apart from one of them who claimed that he/she used the web less than once a month), our analysis shows that the high visual complexity of web pages or the low distinguishability of web-page elements affects them while completing their tasks and causes non-equivalent experience for people with autism and neurotypical people. Therefore, it is possible that these two guidelines would be even more important for people with autism who do not frequently use the web.

To investigate whether people with autism have different processing strategies compared to neurotypical people, we used the mean fixation duration, the total fixation count and the number of transitions between elements as these features have widely been used in the literature [11]. We conducted the analysis by ignoring the fixations which were not located in any element. However, when considering all fixations, we reached the same conclusions. Specifically, the ASD group participants had significantly shorter fixations for the browsing tasks (U=123, z=-1.679 p=.048, r=.27), but they had significantly more fixations for the synthesis tasks (t=3.332, df=36, p=.001, d=1.11) in comparison with the control-group participants.

Saccade data are lost when some fixations are ignored. When considering all fixations, we could also look at other three metrics related to saccades including the mean saccade length, the mean saccade angle and the total saccade length. We are expecting to see significant differences for some of these metrics, especially the total saccade length for the synthesis tasks where the ASD-group participants had significantly higher number of fixations.

In the study, we used an automated tool to compute a visual complexity score for each web page, called ViCRAM [26, 25]. Many approaches are now available to determine the visual complexity of web pages based on the elements of web pages, the pixels of the screenshots of web pages or both [29]. For example, Wu et al. [38] propose a machine learning approach which uses different kinds of features including HTML features, structural features and visual features. However, the ViCRAM tool computes a visual complexity score based on a simple but accurate model and its implementation is publicly available as part of the ACTF Visualisation SDK[10]. Further studies can be conducted with these different complexity algorithms. Similarly, there are also alternative algorithms for the VIPS algorithm that we used for segmenting web pages into their elements [40]. These algorithms use different features of web pages such as their DOM (Document Object Model), visual properties, text densities, and so on. In our study, we preferred to use the VIPS algorithm for identifying the elements of the pages in our study due to its benefits explained in Section 3 and its popularity in the literature. However, further studies can be conducted with other segmentation algorithms.

The number of elements varied among the web pages (M: 26.38, SD: 18.06). As expected, there were higher number of fixations on the visually complex pages (M: 37.50, SD: 20.63) in comparison with the visually simple pages (M: 15.25., SD: 2.36). One could argue that this was the reason for having a significant difference between the ASD and control groups on the visually complex pages. However, even though there were fewer elements on the pages with the low distinguishability level (M: 20.25, SD: 12.84) in comparison with the pages with high distinguishability (M: 32.50, SD: 22.28), we identified a

[10] http://www.eclipse.org/actf/downloads/

significant difference between the ASD and control groups on the pages with the low distinguishability level. Further studies can be conducted to investigate the effects of both the number of elements and the size of elements.

In the present study, we investigated whether the high complexity of web pages or the low distinguishability of web-page elements causes non-equivalent experience for people with autism and neurotypical people by comparing these two groups with the independent T-Test or its non-parametric alternative the Mann-Whitney U test based on the number of fixations on the elements which were not related to the given tasks. However, this study can be extended in the future by conducting other statistical analysis (such as General Linear Model) to further investigate the relationships among multiple factors such as complexity, distinguishability, user groups and tasks.

Finally, our study was not without limitations. Although we tried our best to recruit as many eligible participants as possible, the sample size was not very large. The post-hoc power analysis based on the lowest effect size in the comparative analysis of people with autism and neurotypical people for the visual complexity and distinguishability of web pages revealed that the statistical power was 65%. Even though the statistical power was not very high, we were still able to detect significant differences between people with autism and neurotypical people. Besides this, we could not have a strong balance between our male and female participants. In particular, there were 13 female and six male participants in the control group. Future research may attempt to recruit a larger sample and have a strong balance between male and female participants. Furthermore, although all of the people in the ASD group were verbal and highly-independent, there could be behavioural differences between them. This situation is also possible for the control group. In future studies, additional information (such as demographic information, other disabilities, etc.) will also be collected from participants to offer more insights about the behavioural differences within groups. In particular, it would be worth investigating whether or not two different groups of people with autism from different cultural groups differ from each other when they interact with visually complex web pages with low distinguishability, as there may be differences between cultural groups in raising children with autism [10]. Even though it would have been better to include more web pages in this study to have more generalisable results, we decided to include eight pages because of ethical issues related to participant fatigue and stress [22]. Furthermore, our tasks were related to the Investigate group of the search activities model of Marchionini [24]. Further studies can be conducted with different kinds of tasks, such as the tasks from the Lookup and Learn categories.

6 Conclusion

In this paper, we present the first eye-tracking study with people with autism to empirically evaluate the guidelines related to the visual complexity of web pages and the distinguishability of web-page elements proposed in web accessibility guidelines, for instance in WCAG 2.1 Guideline 1.3 and Guideline 1.4 respectively. Our results empirically support that web pages should have a simple design and their elements should be distinguishable from each other because the high visual complexity of web pages or the low distinguishability of web-page elements affects people with autism when they complete their tasks on web pages and causes non-equivalent experience for people with autism and neurotypical people. Although these two international well-known standard guidelines are suggested, they had not been specifically evaluated with any empirical study which made their applicability questionable. However, this study provides an empirical evaluation of these two guidelines. Therefore, it contributes to the field of web accessibility.

We focused on two different accessibility guidelines in this study. In the future, we plan to focus on other guidelines. For example, we can conduct an eye-tracking study to investigate whether or not inconsistent navigation within a website affects people with autism while completing their tasks (see WCAG 2.1's Success Criterion 3.2.3 Consistent Navigation). In addition to the empirical evaluation of web accessibility guidelines for people with autism, we can also empirically evaluate these guidelines for people with other cognitive disabilities, such as dyslexia.

Conflict of interest

The authors declare that they have no conflict of interest.

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